

REVIEW AND APPRAISAL
of the
FISH PROTECTION PROBLEM ASSOCIATED
WITH THE DIVERSION OF WATER AT THE
TRACY PUMPING PLANT,
CENTRAL VALLEY, CALIFORNIA

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INTRODUCTION

One segment of the Central Valley Project, under construction by the Bureau of Reclamation in California, involves a diversion of approximately 4,600 second-feet of water from the Sacramento-San Joaquin Delta, near Tracy, California. This large diversion of water presents a host of extremely difficult problems related to fish protection.

The fish populations of the Delta have been the subject of investigation for a considerable period of time by various individuals and agencies, particularly the California Fish and Game Department and the U. S. Fish and Wildlife Service. From 1946 to 1949 the Service, with the cooperation of the Bureau of Reclamation, carried on studies in the Delta with particular reference to the then proposed diversion, and a report on these studies was issued in December 1950. 1/

In January 1951, additional studies were inaugurated by Service personnel with the cooperation of the Bureau. These personnel were to study the effectiveness of certain fish screens and appurtenances in a pilot fish-screen structure located in the vicinity of the pumping plant, to carry on such investigations as might be pertinent to the problem of fish protection, and to advise, assist and consult

1/ Sacramento-San Joaquin Delta Fishery Resources: Effect of Tracy Pumping Plant and Delta Cross Channel, by Erkkila, Moffett, Cope, Smith and Nielson. Special Scientific Report: Fisheries No. 56, U. S. Fish and Wildlife Service, Washington, December 1950.

with Bureau personnel in the design of the permanent fish protection facilities.

Concurrently with the inception of these additional studies a committee or group, known as the Tracy Advisory Council, was formed to meet periodically and to review the progress on the studies, to interpret and analyze the data assembled, and to determine the direction of the investigations.

At the inception of these studies, although no definite deadlines were established, it was anticipated that decision on the design of the permanent structure would be crystalized within one or at the most two years, and that construction would follow shortly thereafter.

By the winter and spring of 1952-53, no definite plans had been formulated in regard to the design of the final structure. Therefore, the Fish and Wildlife Service after consultation with other interested parties detailed an appraisal team to Tracy in April 1953, to review the accomplishments to date and to recommend future action. This team, the authors of this report, consisted of Joseph T. Barnaby, Regional Staff Biologist, Scott H. Bair, Hydraulic Engineer, and Gerald B. Collins, Fishery Research Biologist all of the Fish and Wildlife Service.

During the course of review and appraisal of the project, the fish-protection facilities and the related studies, the authors have been assisted by Daniel W. Bates and George O. Black of the Fish and Wildlife Service, B. R. Bellport and Russell Vinsonhaler of the Bureau of Reclamation, Donald H. Fry of the California Fish

and Game Department and by William Cheney of the Pacific Gas and Electric Company. The reports by Erkkila et al 2/, by Calhoun 3/, and by Bates and associates 4/, have been particularly helpful and in the preparation of this report the information from those reports has been used extensively, usually without specific credit.

To all those mentioned and to the many others who have cooperated with us, we wish to express our appreciation and thanks.

2/ Ibid

3/ Distribution of Striped Bass Fry in the Sacramento-San Joaquin River System in 1951 in relation to water diversions, by A. J. Calhoun, California Department of Fish and Game (In press)

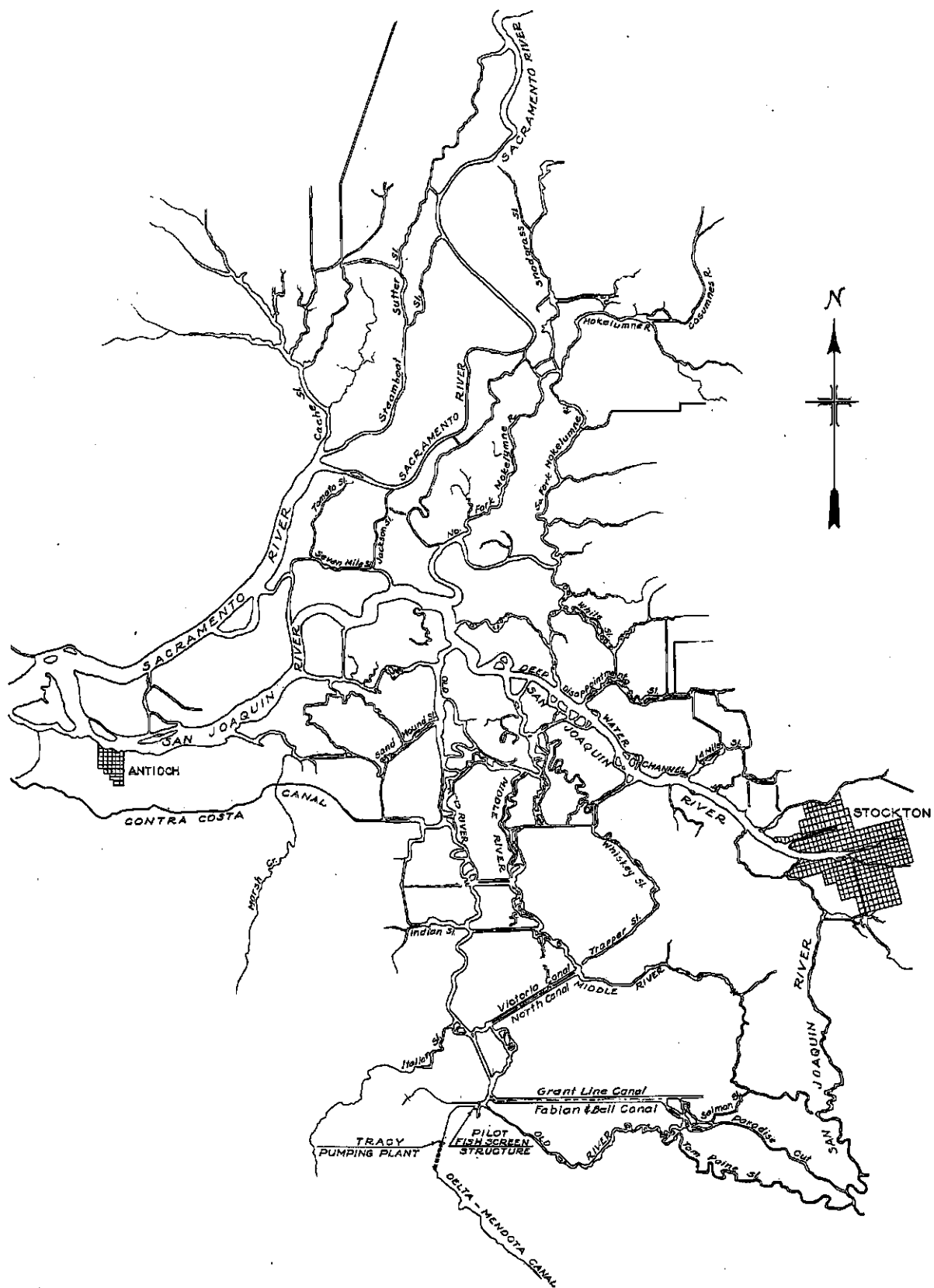
4/ Studies of the Delta-Mendota Canal Fish Protective Facilities, 1951-1952, by Daniel W. Bates and Associates. (In manuscript)

DESCRIPTION OF PROJECT

The Sacramento River flowing southward and the San Joaquin River flowing northward join in a common terminus known as the Sacramento-San Joaquin Delta (See Figure 1), which is a maze of 500 miles of canals forming the uppermost extension of San Francisco Bay. In the Delta, the waters of the Sacramento and San Joaquin Rivers are thoroughly mixed with tidal influence contributing greatly to the mixing action. Salinity in the Delta varies within seasons and from season to season, however, in the major part of the Delta the water is fresh or only slightly brackish.

The intake works of the Delta-Mendota Canal, known as the Tracy Pumping Plant, are located some 6 miles from the City of Tracy. A diversion canal takes off from a slough on one of the channels in the Delta known as Old River and extends for 2.3 miles to the pumping plant. At the pumping plant are located six large pumps, each with a capacity of from about 680 to 830 second feet, which pump water to the main canal a vertical distance of some 197 feet. The capacity of the pumps varies with variations in head and with the number of pumps in operation, the total capacity of all six pumps being ~~approximately~~ approximately 4,600 second-feet.

Flow in the intake canal varies not only with the number of pumps in operation but also as a result of tidal action. The length of the intake canal from Old River to the pumping plant is approximately 2.3 miles and the width of the canal at its mean



CHANNELS OF THE DELTA AREA
SAN JOAQUIN & SACRAMENTO RIVERS

water surface is about 200 feet. The tidal range varies considerably with an average range of about 3 feet and a normal maximum range from the low water to the high water of a given tidal cycle of about 3.6 feet. Thus, during a period from low water to high water, a normal maximum of nearly 9,000,000 cubic feet of water enters the intake canal during approximately six hours as a result of tidal influence. This amounts to an average inflow of over 400 second-feet during such periods.

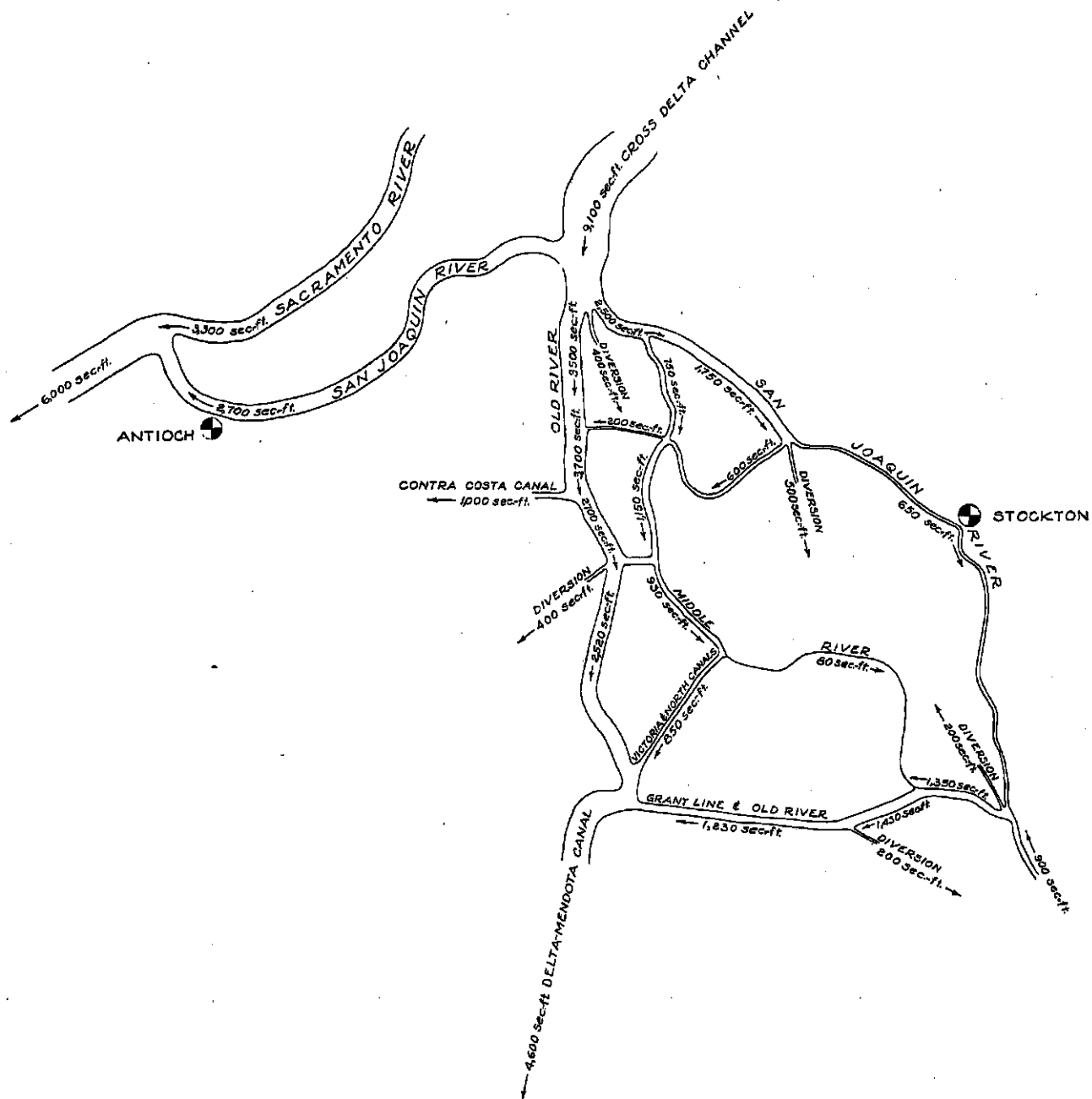
Adding the total diversion inflow to the inflow due to tidal action gives a total inflow (during periods of flood tide) in excess of 5,000 second-feet. Considering the possibility that the pumps may deliver in excess of their rated capacity and that there may be an above-normal maximum inflow from tidal action, it would appear that a figure of 5,200 second-feet should be used when considering fish-screen requirements, based on the assumption that the location of the fish screens is to be near the river end of the intake canal.

The diversion of water at the Tracy Pumping Plant will have a pronounced effect on the flow pattern in the canals of the Sacramento-San Joaquin Delta. In general the flow from the Delta to the ocean will be reduced, and there will be a drift or flow of water from the northern side of the Delta to the southern side (to the intake of the Tracy Pumping Plant). This flow will vary considerably in volume and direction from time to time during the year, and to some extent from year to year depending primarily on such factors as magnitude of flows in San Joaquin and Sacramento Rivers, and amount of water diverted.

The Bureau of Reclamation made a study of the average flow patterns in the Delta to be expected under varying conditions of river flows and irrigation demands. Figures 2 and 3 have been prepared from data and grids of flow conditions resulting from this study.

In Figure 2 is presented the average condition that would probably exist in April. Under this average condition, it is assumed that the diversion at Tracy would be about 70 percent of capacity, or 3,200 second-feet, which together with diversion of 200 second-feet for the Contra Costa Canal and 1,000 second-feet for private diversions in the Delta area, comprise a total diversion of 4,400 second-feet of the total assumed flow of 5,000 second-feet contributed by the San Joaquin River. As will be noted in Figure 2, only 600 second-feet of the 5,000 second-feet in the San Joaquin River above the Delta is contributed to the total flow of 10,000 second-feet in the San Joaquin River at Antioch, the balance of 9,400 second-feet coming from the cross-delta channels. Thus, under these assumed conditions, 88 percent of the ^{flow contributed to Delta by} San Joaquin River flow would be diverted from the Delta, of which 64 percent is taken by the Tracy Pumping Plant.

Later in the season as the demand for irrigation ^{increases} and the flow of the San Joaquin River decreases, the flow from the northern to the southern side of the Delta becomes more pronounced. As shown in Figure 3, during the months of July and August total diversion from the Delta area amounts to some 7,300 second-feet. Of this amount, 6,400 second-feet is contributed by flow from the Sacramento River and the balance of 900 second-feet is obtained by utilizing the entire flow of the San Joaquin River. Total average flow of the Sacramento



SAN JOAQUIN DELTA AREA
PICTORIAL FLOW PATTERN FOR JULY & AUGUST

River during the months of July and August is some 12,400 second-feet. Thus, during this period, diversion within the Delta accounts not only for the entire flow (900 second-feet) of the San Joaquin River but 52 percent (6,400 second-feet) of the entire flow of the Sacramento River. Such a flow pattern in the Delta obviously would have a marked affect on the fish life of the area.

Flow conditions as shown in Figures 2 and 3 are assumed average conditions. While it is true that in about one-half the years flows in the San Joaquin and also the Sacramento Rivers would exceed these averages and hence result in a lesser effect on fish life, it is likewise true that in about one-half the years flows in the San Joaquin River would be below these averages and hence result in a much greater effect on fish life. In this connection, it is not unusual for the flow of the San Joaquin River at its confluence with the Delta to be zero during the late summer months and consequently all water diverted from the Delta must be obtained from Sacramento River flow.

FISH POPULATIONS AFFECTED

The Delta is extremely rich in fish fauna, both as to species and numbers. Some 23 species are known to be present, of which over half have been taken at the entrance to the intake canal of the Tracy Pumping Plant. The four species of primary importance are the king salmon, the striped bass, the shad, and the catfish.

King salmon utilize the Delta channels as migration routes from the spawning and rearing areas in the tributaries of the Delta to the ocean, and again as adults on their return from the ocean to the spawning areas. In this study we are not concerned with the adult fish, although the effect of the introduction of Sacramento River water into the San Joaquin watershed should not be overlooked in subsequent studies of the migration pattern and distribution of adult salmon.

The salmon fingerlings migrating to the ocean from both the Sacramento and San Joaquin Rivers will very definitely be affected by the diversion of water at Tracy 5/. Little is known as to the exact means by which a salmon fingerling finds its way from its rearing area to the ocean. These fish are making the journey for the first time in their life. That the migration is not merely a passive drifting with the currents is quite apparent in those instances where salmon must pass through one or more large lakes on

5/ The term "Tracy", as used in this report, refers to the general area in which is located the Tracy Pumping Plant, the intake canal and the pilot screen structure.

their seaward journey. Yet at least in moving water, the currents must play a vital role--they must serve as guide lines to the fish on their migration. If the flow of water terminates as it normally does in the ocean, or inlet thereof, the fish reach the ocean. But on the other hand if the flow is diverted into a diversion canal the young salmon, voluntarily or otherwise, proceed or endeavor to proceed down the diversion. Thus we take as a basic premise--that as the water flows, so go the salmon fingerlings, unless they are diverted by means of fish protection facilities.

It is pertinent to review the time of appearance of fingerling salmon in the Delta and their size range. From extensive sampling carried on during 1947, 1948, and 1949, it appears that the majority of the Sacramento River fish migrate seaward during February, March and April with the peak of the migration taking place during March. It appears that the majority of the San Joaquin fish migrate seaward during April, May and June, with the peak of the migration taking place in May. Seaward migrants from both watersheds may be present in the Delta in some years both before and after the periods indicated, depending on seasonal variations. Thus it would appear that protection must be afforded salmon fingerlings at Tracy from the beginning of the irrigation season in January or February until the end of June. It further appears from the extensive literature on the subject that the value of the Sacramento-San Joaquin salmon runs is such as to make unnecessary a detailed justification for their protection. However, it is pertinent to note that the average annual commercial catch of salmon attributable to Central Valley streams is about 5,600,000 pounds

and in addition these fish support a sport fishery, both in the Delta and the ocean, of considerable magnitude.

The size range of Sacramento seaward migrants is from 1.4 inches to 3.5 inches, and that of the San Joaquin seaward migrants from about 2.7 to 3.3 inches. Thus it would appear that any method of screening that would reasonably protect fingerlings with a minimum length of about 1.5 inches would be satisfactory for these fish.

Striped bass use the Delta not only as a migration route, but also as a spawning and rearing area. Spawning takes place during April, May and June with the peak occurring during the last week of April to the middle of May. Time of spawning is influenced by water temperature and varies from year to year. The eggs, which are about $1/25$ of an inch in diameter when spawned, hatch out in about two days and the fish make rapid growth, reaching a length of about $1\frac{1}{2}$ inches by the latter half of July. The adults utilize virtually all the Delta as a spawning area, however, the lower areas are apparently more heavily populated than the upper areas. By the middle of September nearly all the young striped bass have left the Delta. It would thus appear that young striped bass are vulnerable to the effects of the diversion at Tracy from about April until the middle of September. Calhoun has estimated that only 10 to 15 percent of the young striped bass are present in the upper delta area the waters of which would be affected in whole or in part by the diversion at Tracy.

The striped bass fishery is exclusively a sport fishery, but is one of major importance. It has been estimated by the California Fish and Game Department that from $5\frac{1}{2}$ to $6\frac{1}{2}$ million pounds of these fish are taken annually by nearly a quarter of a million fishermen.

At the present time no satisfactory means are available for the protection of striped bass eggs or larvae. However, it normally is possible to successfully protect fish with a minimum size of about 1 to $1\frac{1}{2}$ inches. Thus the immediate problem of devising fish-protective devices for this species is narrowed to the period from about the end of June to the end of August or middle of September and to fish with a minimum size from 1 to $1\frac{1}{2}$ inches in length.

Shad are also an important species in the Delta producing a take of some 600,000 pounds annually. These fish, like striped bass, use the area not only as a migration route but also as a spawning and rearing area. Spawning takes place in the spring of the year. The young fish grow rapidly having an average length of about 0.8 inch by the end of June, about 1.3 inches by the latter part of July, about 1.8 inches by the middle of August and about 2.2 inches by the end of August. Larval and juvenile shad are present in the Delta from about the middle of July until at least November, however, it appears that the bulk of the fish have left the area by the end of September.

Catfish are important both commercially and in the sport fishery. In 1951 the area produced approximately 240,000 pounds to

the commercial fishery and over 2,000,000 fish to the sport fishery. These fish being fresh-water fish, spend their entire life in the Delta and fish of virtually all sizes are subject to the influence of the diversion of water.

A number of other species of fish would also be affected by the diversion of water at Tracy, however, while collectively they are of some importance their individual importance is overshadowed by the species discussed.

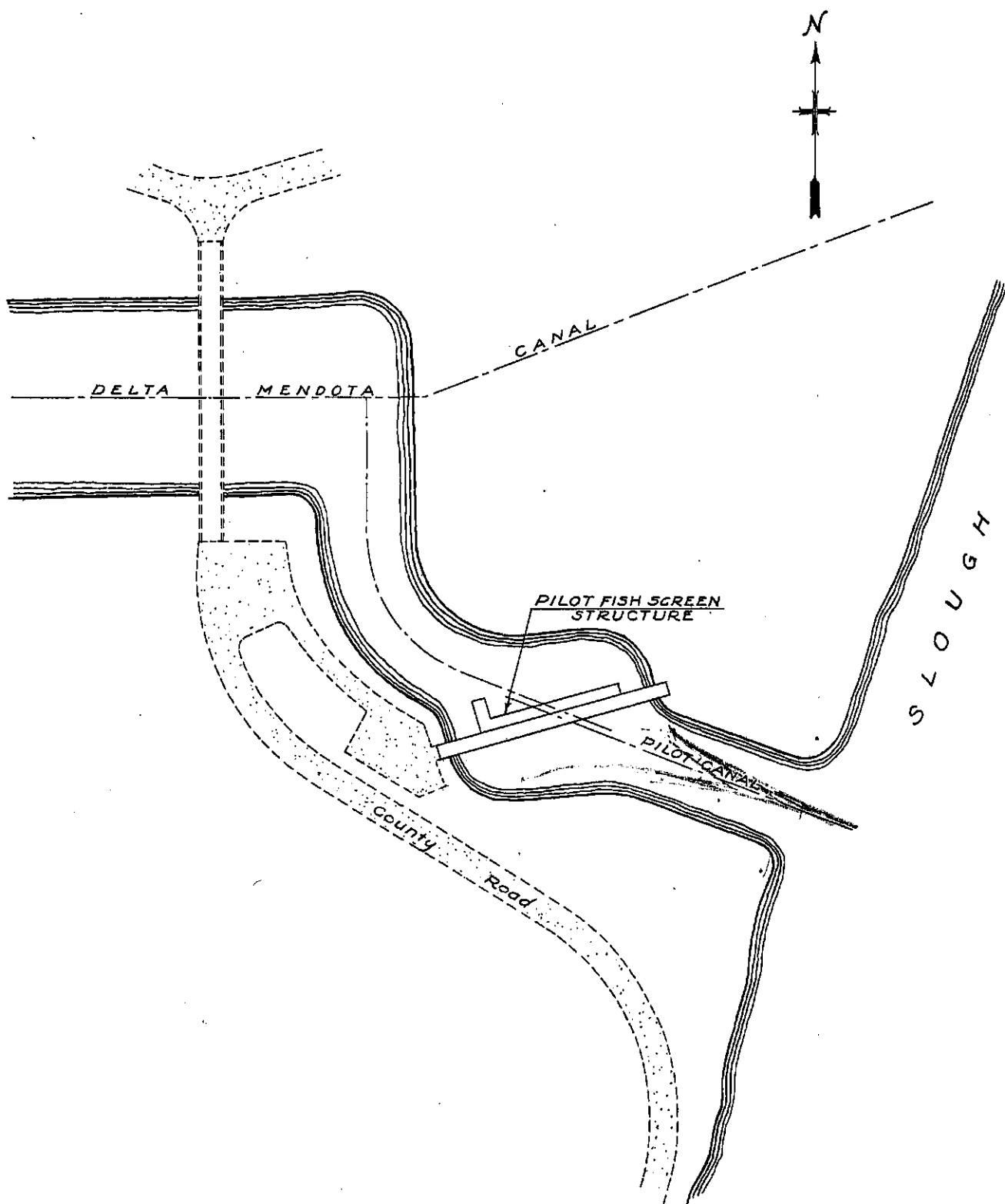
In summation, the diversion of water at Tracy would affect populations of fish of considerable commercial and recreational value. King salmon, striped bass, shad, and catfish are the most important of over twenty species of fish that would be affected. Juvenile fish are present in the Delta the year round with the period of greatest abundance from February to September inclusive. All sizes of juvenile striped bass, shad and catfish, down to and including eggs, would be affected by the diversion of water at Tracy, therefore, the fish protective devices should be designed to protect the smallest size of fish possible.

SCREENING AND BYPASS PROBLEM

From the very inception of definite planning for the diversion of water at Tracy it was realized that some facilities would have to be provided for screening fish from the water to be diverted, and for bypassing these fish (either by flume, conduit, barge, or tank truck) to a point sufficiently distant downstream from the diversion.

After some preliminary consideration of the screening problem, it was tentatively decided that the final structure would entail some form of mechanical screen. Personnel of the Bureau of Reclamation then decided to test two such types of screens, viz., belt screens and perforated-plate screens, in a pilot structure. Work on this structure (See Figures 4 and 5) was started by the contractor September 15, 1950 and completed October 3, 1951.

The pilot structure is of timber construction, separated by planked division walls into 12 water passages or bays in which are installed a combination of mechanically-operated and stationary screens, including one stationary screen with a mechanical cleaning device. The structure is located some 300 feet downstream from the intake of the pilot channel, as measured along the centerline of the channel, and is so oriented that the axis of the structure is at an angle of 53 degrees in a clockwise direction from a line drawn at right angles to the channel centerline. Beginning at the end of the structure nearest the channel intake, the screen installations consist of a series of 9 vertical stationary screens, 2 belt-type



PILOT CANAL & FISH SCREEN STRUCTURE
DELTA MENDOTA CANAL INTAKE



Figure 5. Pilot screen structure, as observed from upstream side.

mechanical screens, and an inclined stationary screen with mechanical cleaning device. Total length of the structure at deck level, including the timber bulkheads at each side of the section of screened openings, is approximately 255 feet and the overall height of the structure from bottom of the channel to deck level is 25 feet 8 inches.

The inclined stationary screen, located in the furthestmost downstream screen bay, consists of 6 interlocking screen panels each 5 feet in height and 11 feet 7 inches in width, so as to provide a single screen panel measuring 30 feet along the slope when installed. The screen panels are covered with 16-gauge steel plate with punched holes 0.156-inch diameter spaced on 0.219-inch centers in an equilateral-triangle pattern. The mechanical cleaning device consists of ^a steel wiper blades attached to a ^{chain} ~~chain~~ at each side of the screen panel, with the blades traveling upward ^{over the face of the panel} over the face of the panel. Guides are provided to permit placement of the assembled screen panel at either an angle of 45 degrees or 32 degrees with respect to the floor of the structure.

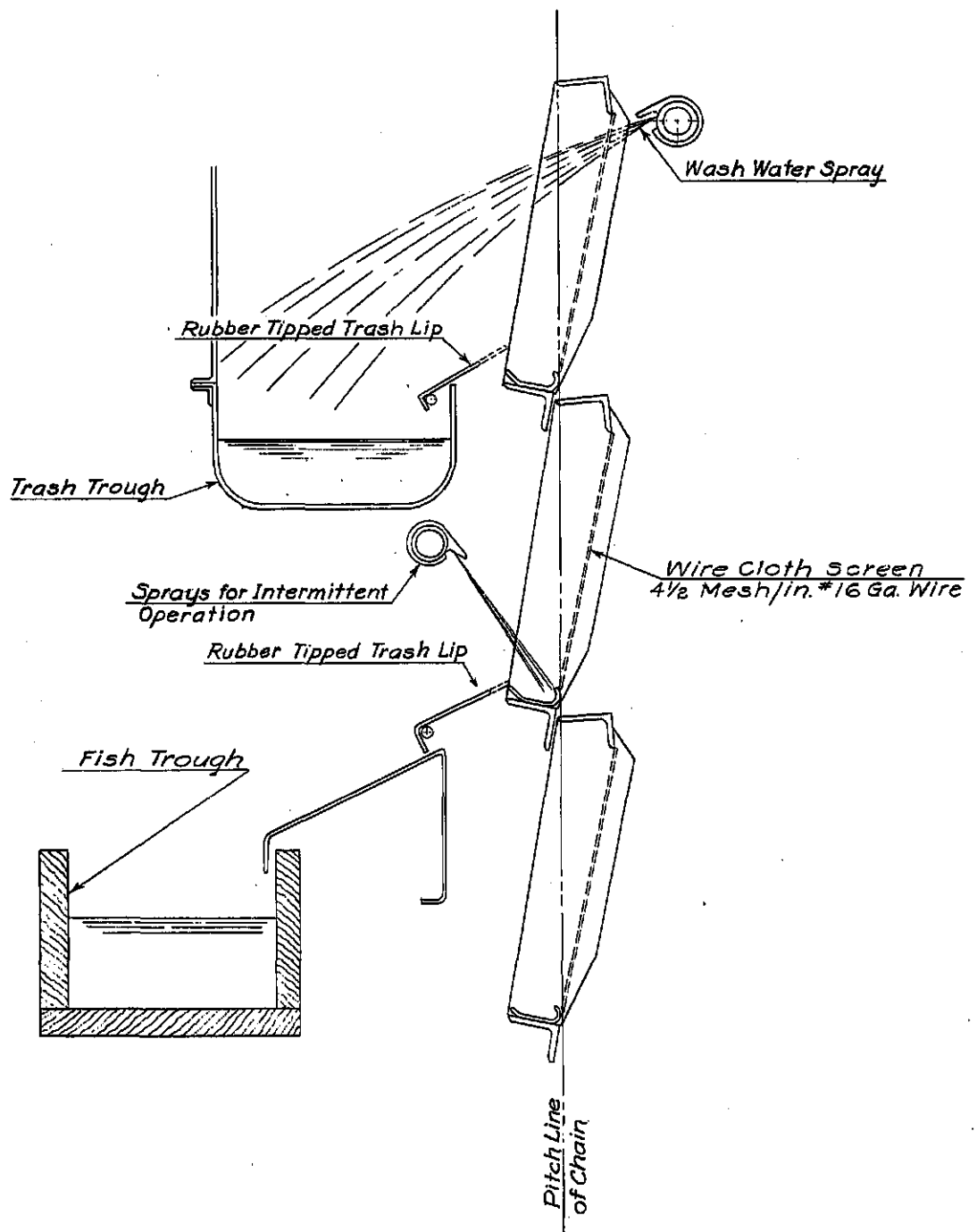
The 2 belt-type mechanical screens, located in the bays adjacent to the perforated-plate screen, are of Link-Belt Company manufacture and are composed of screen trays each 10 feet in width and 2 feet in height covered with 16 gauge $4\frac{1}{2}$ mesh per inch wire cloth, galvanized after weaving. Wire cloth of these specifications afford a clear opening between individual wires of 0.159 inch before galvanizing. Spray nozzles, operating under a pressure of 90 to 100 pounds per square inch, are provided for cleaning the screen trays as they approach the upper limit of their vertical movement. The

jets also serve to wash small fish from the ledge at the bottom of the trays into the wash water flume.

Subsequent to the original installation, one of the Link-Belt screens was modified by the addition of a fish-collecting cup on the ledge of each basket and provision of a second set of spray jets expressly for the purpose of flushing small fish from the collecting cups (See figure 6). The latter change necessitated the addition of 2 screen trays, since the head shaft required raising to provide space above deck level for a second set of spray jets.

The 9 remaining screen bays are provided with stationary vertical screens, each consisting of 4 interlocking screen panels some 5 feet 6 inches in height and approximately 11 feet in width. The panels are covered with 19 gauge 5 mesh per inch wire cloth galvanized after weaving, with a clear opening between individual wires of 0.159 inch before galvanizing. As originally constructed, the screen panels had to be uncoupled at deck level for cleaning. Hoisting facilities as provided would not permit raising of the assembled screen panel to its full height. Furthermore, washing of the screens had to be accomplished by use of a hose. This set-up was later changed by modifying the gantry crane to permit raising of the fully-assembled screen panel to the operating deck, and a series of jets was provided on the downstream side of each screen panel to afford a better means of cleaning the vertical screen panels.

As a means of preventing accumulations of larger trash from reaching the screens, a trash rack with a clear space between bars of 2 inches is provided across the front of the structure. Originally,



MODIFIED LINK BELT SCREEN
FISH COLLECTOR CUPS & WASH WATER FACILITIES

the trash racks were installed such that the bottom of the rack sections was some 12 feet in elevation above the bottom of the canal, but, due to the difficulties encountered with submerged waterlogged snags, the trash racks were extended to the bottom of the channel.

Incorporated into the structure is a series of nine fish-collector pipes or risers placed along the face of the screens at screen bays 1 to 8, inclusive. There is a collector pipe placed at both sides of the sloping perforated-plate screen; one collector pipe is located between one of the two Link-Belt screens and the sloping perforated-plate screen, immediately in front of the seal plates at the ends of the screen trays; one collector pipe is located between the two Link-Belt screens; one collector pipe is located between one of the Link-Belt screens and one of the vertical screens, essentially flush with the face of the vertical screen; and the remainder of the collector pipes are located between the vertical screens. The collector pipes at the inclined perforated-plate screen are 6 inches in diameter and are provided with 12 fish ports each measuring $2\frac{1}{4}$ inches by 6 inches and placed 2 feet 5 inches on centers. The other seven collector pipes are of variable cross-section, with 13 fish ports each 2 inches by 6 inches provided at 1 foot 6 inches on centers along the pipes. The fish ports of the seven vertical collector pipes are provided with slide covers for adjustment of the size of orifice.

Each of the nine collector pipes is connected to a 5-inch bladeless impeller-type centrifugal pump, except for the sloping

collector pipe along the right side of the perforated-plate screen and the vertical collector pipe between the perforated-plate and Link-Belt screens, which pipes are connected to a single pump. The individual pumps have a discharge capacity of 650 gallons per minute at a 16 foot head. The pump discharge lines are connected to a manifold pipe for conveyance of fish-bypass flow to a holding pond.

In January 1951, at which time the pilot screen structure was under construction, personnel of the Fish and Wildlife Service were assigned to the project to evaluate the effectiveness of the screens under test, to assist in the design of the permanent fish protection facilities, and to carry on such corollary studies as might be deemed necessary. Observations during 1951 and 1952 resulted in the following conclusions: (1) A major debris problem prevails in connection with the provision of fish screening at the Tracy pumping plant; (2) The perforated-plate screen as installed in the pilot screen structure was unsatisfactory and its use in the prototype was not recommended; (3) Stationary vertical screens were unsatisfactory and their use in the prototype was not recommended; (4) Belt screens used in a manner usually referred to as "high velocity" screening 6/ were reasonably satisfactory, except that striped

6/ In normal or typical fish-screen operation, the screen stops the downstream passage of fish, without the fish ever coming into contact with the screen, and the fish find a bypass leading back to the river. In this procedure, the velocity of approach to the screen must be less than the swimming ability of the fish. In "high-velocity" screening, the velocity of approach is purposely designed to be greater than the swimming speed of the fish so as to insure impingement of the fish against the screen. The fish are then brought to the surface by the moving screen and washed off the screen into a bypass.

bass subsequently went into a condition referred to as "shock"; (5) A major problem exists in connection with the elimination or the cure of "shock" in striped bass; (6) By-passing fish by means of ports as installed in the pilot structure was not satisfactory, and (7) The most practical method of transporting fish from the project area to a safe point of release downstream is by the use of tank trucks.

The personnel at the project have reviewed and considered a variety of screening methods other than those incorporated in the pilot structure, including sound, light, electricity, drum screens, sloping belt screens, belt screens with apron collector and louvers. Of the various methods considered, louvers appeared most worthy of detailed investigation. Project personnel constructed a test flume some 5 feet wide and 25 feet long (See Figure 7) and ran a considerable number of tests on the effects of velocity, louver design and spacing, and angle between the line of louvers and the walls of the flume, all with respect to the action of salmon fingerlings. It was found that louvers had some merit in leading fish into a bypass, while at the same time permitting the major part of the water to pass through the spaces between the louvers. As a portion of the fish in virtually every test did pass through the louvers (i.e. were not bypassed), tests were also made with louvers with a facing of wire screen.

It was recognized that the test flume had certain hydraulic deficiencies and that, although the tests appeared to indicate that louvers might have some merit, additional studies should be conducted on the louver principle before any definite conclusions could be reached.

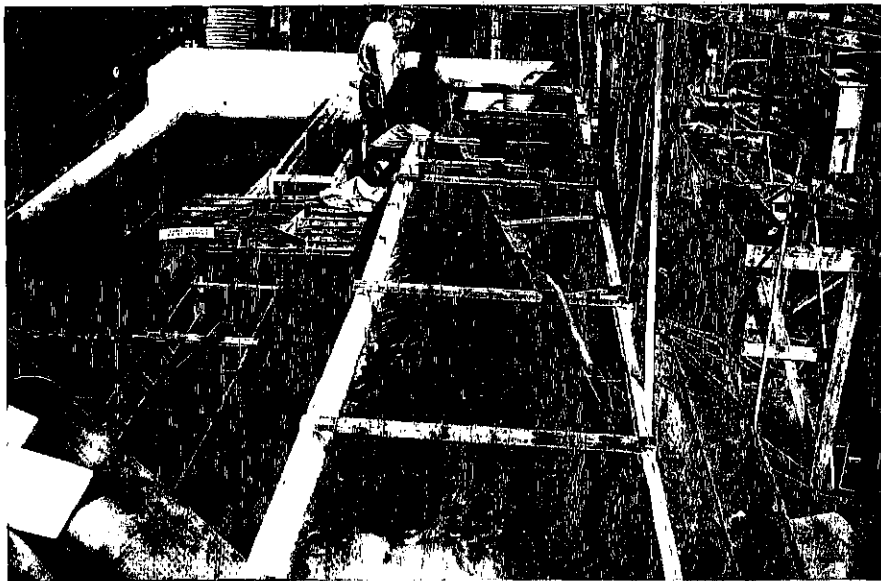


Figure 7. View of test flume looking downstream. Line of louvers extends from near right to far left of flume.

In connection with the cure of shock in striped bass, preliminary studies have been made and it is planned to carry on additional studies during the 1953 season. Studies in connection with the transportation and handling of fish are also under way.

REVIEW OF PROGRESS TO DATE

A review of the work of the personnel assigned to the study of the fish-protection facilities at the Tracy Pumping Plant reveals that during the period January 1951 to March 1953 the following studies have been carried on:

1. Evaluation of perforated-plate screen
2. Evaluation of belt screens
3. Evaluation of vertical screens
4. Evaluation of fish-collection system at pilot structure
5. Vertical stratification of fish (other than salmon) in Old River, and at pilot screen structure
6. Population estimates and species variation at pilot screen structure
7. Swimming speed of fish
8. Mortality of striped bass as a result of shock
9. Treatment of shock in striped bass
10. Effect on fish passing through Tracy Pumping Plant
11. Relative degree of clogging of wire cloth of selected sizes
12. Consideration of other types of fish screens, with special attention given to louvers
13. Flow pattern in Delta
14. Striped bass and salmon populations
15. Temperature regime in Delta
16. Fish transportation problems
17. Debris problems

18. Problems in caring for fish during interim period prior to installation of the prototype fish protection facilities.

The intensity of the study of the various items enumerated above varied with their respective importance insofar as the problem at Tracy was concerned and with the time available for each of the several studies. Studies on some phases of the problem have been completed, while others are in need of further investigation. This latter fact is recognized by the personnel at Tracy.

In reviewing the Tracy fish-protection problem, the authors are impressed with the magnitude of the problem as a whole and particularly with the change in scope of the problem from the time when the fishery personnel were detailed to the project in early 1951 to the present time. Initially, the primary detail of the crew was to determine whether belt-type screens or perforated-plate screens should be incorporated in the final structure. It was soon found that the screening facilities, as installed, were unsatisfactory. Thus, the scope of the problem changed to (1) deciding which, if any, screening devices currently used might be satisfactory, (2) attempting to develop new types of screening devices, and (3) attempting to obtain precise information on the cause and cure of shock in striped bass.

It is our opinion that the biologists assigned to the Tracy project have performed a creditable job and have shown considerable initiative and originality in coping with and solving many of the unexpected and difficult problems that have developed in connection with the assignment.

The rapid development of the Tracy Project, insofar as water demand is concerned, has magnified the fish-protection problem, particularly the phase related to the interim period pending construction of the prototype fish-protection facilities. This phase of the problem is accentuated by the lack of immediate decision with regard to prototype fish screen design and of solution of the problem of shock in striped bass. These uncertainties naturally prolong the period that dependence will have to be placed on the temporary fish-protection facilities.

A considerable amount of study is needed prior to the time when a final decision can be made as to the design of the fish protective devices in the prototype structure. With the rapid development of the project it appears that a maximum demand for water will prevail within a few years, hence it is imperative that the studies be prosecuted with all possible vigor in order that solutions will be at hand and final design and construction may commence at the earliest possible date. It must be kept in mind that it will be approximately 2 3/4 years after final decisions are made on functional design that the prototype structure will be ready for operation.

POSSIBLE SOLUTIONS TO THE PROBLEM

From a consideration of the biological and hydrological conditions at Tracy and vicinity, it appears that some method of satisfactorily screening and transporting fish as small as 1 to $1\frac{1}{2}$ inches in length must be devised if the fish populations of the Delta are to be reasonably protected.

It further appears that if fish 1 to $1\frac{1}{2}$ inches in length are to be kept from being impinged against the screen, the approach velocity to the screen must not exceed 0.5 feet per second. In the event that some or all of the striped bass are impinged on the screen, and subsequently collected and transported, it appears that they must be satisfactorily treated for shock. It is entirely possible, in fact probable, that some degree of shock will be induced in fish of this species even without impingement, merely by passing through the bypasses and in being transported from the point of collection to the point of release down river.

While the fish-collection system at the pilot screen structure was found inadequate, we feel that a more suitable design could be developed that would be reasonably successful in collecting fish. In view of this belief, we have not ruled out a system of ports and risers as a means of collecting fish.

In contemplating the possible solutions to the problem, a wide variety of screening methods including belt screens, stationary screens, drum screens, louvers, electric screens, lights, and sound have been considered. However, only the types thought to have some reasonable chance of success at Tracy are subsequently discussed.

Belt Screens, with low approach velocity.

Belt screens have proved themselves to be admirably designed to cope with the debris situation which prevails at Tracy. However, the problem of bypassing the fish which have been stopped by the screens has not been solved. The bypass system, as incorporated in the pilot screen structure, proved to be unsatisfactory for a variety of reasons, the three principal ones being small size of ports, low velocity of flow into the ports and high approach velocity to the screens. It is believed that if these and other faults were corrected that the majority of the fish over a length of approximately one inch, could be satisfactorily bypassed. Such a design would be based on a maximum approach velocity of about 0.5 feet per second.

Belt Screens, with high approach velocity.

A method of screening not in frequent use, but one that has been tried with some success at Tracy is "high-velocity" screening. This method has the distinct advantage of being relatively low in cost (in comparison to a normal belt screen installation) because of the lesser number of screens needed for a given flow. In this type of screening, it is imperative that the velocity of approach be sufficiently high to insure that the fish will be promptly impinged against the screen, and that it not be so great as to injure the fish. It is important that the screens be operated continuously and that the rate of travel of the screens be such that the fish are not impinged on the screen for an undue length of time. These conditions must be determined for the sizes and species of fish at the location of the proposed screen site. Data obtained

at Tracy indicate that in the case of young striped bass even a minimum of contact with the screens brings on a condition referred to as "shock" which results in the death of large numbers of fish in a few hours. Thus a primary problem related to this type of screening at Tracy is the cure or treatment of shocked fish.

It has been noted that with this method of screening it is imperative that the fish be promptly impinged on the screen. Owing to the variations in canal flow at Tracy, due to tidal influence and changes in number of pumps operating, some system of gates would have to be incorporated in the structure so as to make possible the ready closure or opening of the screen bays. Such control would be necessary in order to vary the number of open bays in accordance with flow variations.

Belt Screens, with variable velocity.

In view of the importance of providing a suitable uniform high velocity of approach when high velocity screening is utilized, and the problems involved in obtaining such a condition at Tracy, a combination of high and low-velocity screening would seem preferable, provided of course that the problems associated with each method could be reasonably resolved. Fish-collection facilities would consist of both a system of ports and risers and a system of spray jets and fish flume so as to provide suitable bypass facilities at all times.

Louvers.

Essentially the louver screen consists of a series of vertical baffles, somewhat like a trash rack, placed diagonally

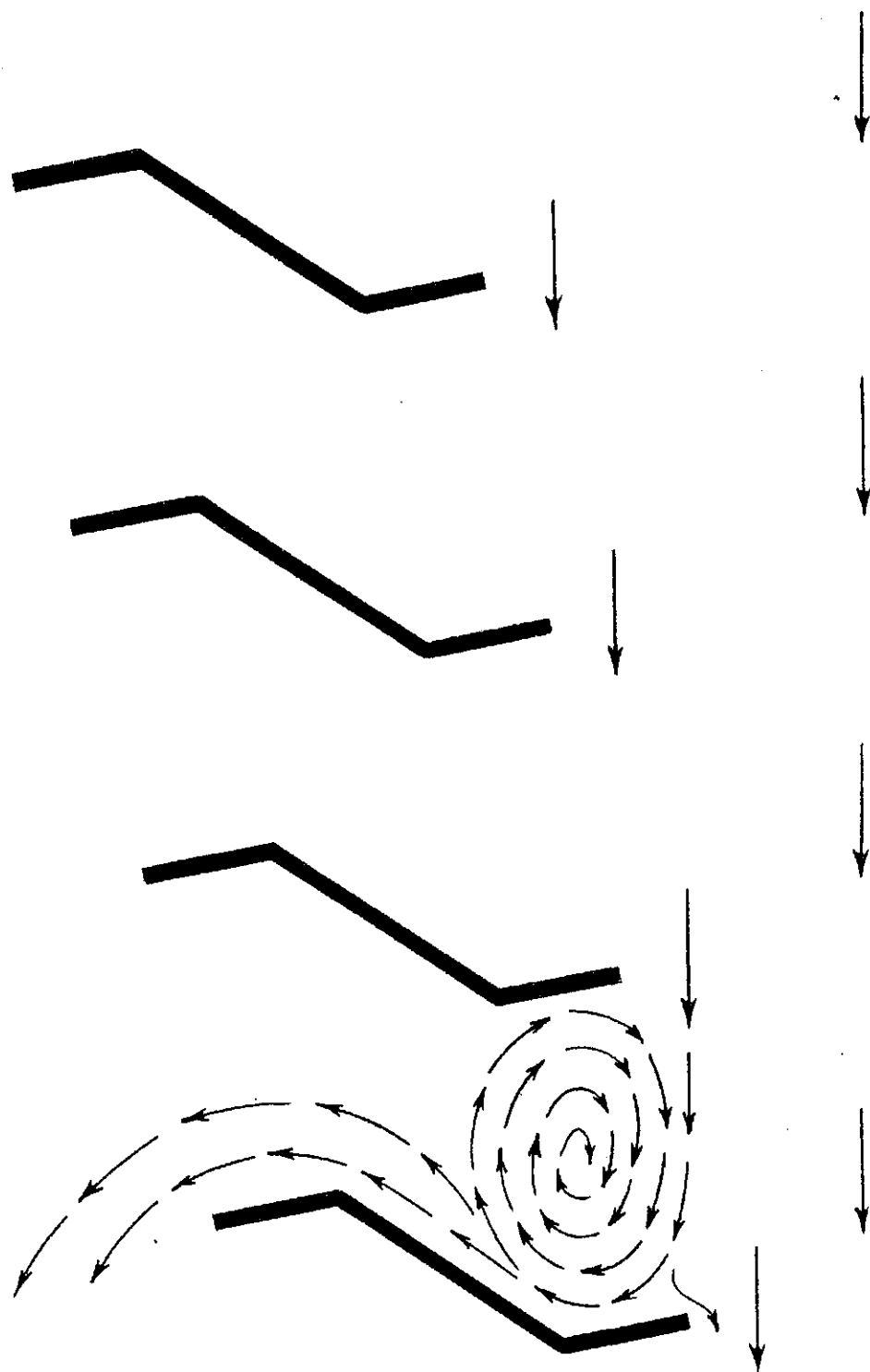
across the channel with an opening or bypass at the downstream end of the structure. Fish are reluctant to pass through the openings between the louvers and hence tend to swim away from the line of louvers and finally are carried into the bypass. A large number of tests with louvers were made in a test flume at Tracy and, while a majority of the fish were bypassed, a portion of the fish in virtually every test were carried through or swam through the louvers. Tests were made during the hours of darkness with results comparable to those obtained during daylight hours. From these tests it appears that fish were able to detect and to an extent avoid the louvers in the test flume during total darkness.

If louvers are to be given further consideration, studies on the reaction of the small fish to the louvers should be made on a much larger scale than can be done in the present test flume. In the final structure, the line of louvers would need to be hundreds of feet in length and the reaction of the fish would need to be repeated many times before entering the bypass. There are two possible courses of action: (1) large scale field tests, or (2) tests in a larger specially-designed experimental flume. In our opinion, the latter method of approach would be more flexible and would provide more definite information. The experimental flume suggested should be designed by technically qualified hydraulic engineers familiar with model-study investigations and should have the following characteristics:

1. Of sufficient size to accommodate a line of louvers approximately 100 feet in length
2. Velocity of flow in the test flume upstream from the line of louvers as uniform as possible.
3. Ability to change the velocity of flow in the test flume from about 1 foot per second to about 5 feet per second
4. Width of bypass to be approximately 6 inches
5. Ability to change ratio of effective width of test flume to length of line of louvers from approximately 1 to 3.5 to approximately 1 to 15
6. Depth of water in test flume to be 1.5 feet minimum, preferably 2 feet
7. Louver design
 - a. Spacing, not to exceed 4 inches
 - b. Ability to change position or angle of louvers with change in No. 5.

A thorough study has not been made of the hydraulic action of the louvers. However, it appears that the condition desired is for each louver to "peel-off" as thin a slice of water as possible along the upstream surface of the louver (See Figure 8). The most effective cross-sectional shape and position of the louvers, in relation to the direction of flow, should be determined by hydraulic studies.

Following these hydraulic tests and the design and construction of a new experimental flume, tests with salmon, striped bass and other species should be carried on to determine the degree



FLOW PATTERN IN VICINITY OF LOUVERS

of efficiency of the louvers. It could then be determined if louvers had sufficient merit to be incorporated in the final design and whether they could be used alone or would require high-velocity belt screens in addition thereto.

Electric Screens.

There would be several important advantages to the use of electricity for screening. The initial cost of installation would be much less than for any other type of screening, there would be no cleaning problem, maintenance would be relatively simple, and the electrodes would offer very little interference to the flow of water in the canal.

Laboratory experiments in electrical fish guiding currently being conducted by the Service in Seattle have been very encouraging. Preliminary field experiments will probably begin late in the fall of 1953 or in the spring of 1954. It is hoped that by the summer of 1954 enough information will be available to indicate whether or not a full scale field trial should be made at Tracy.

Fish Collection.

With any type of bypass in a screen structure, it is our belief that the most satisfactory method would be to induce a flow through the bypass system by gravity. This could be accomplished by draining the water into a collection pool below river level and by pumping the water from this pool from behind a screened section.

Final design of the fish-collection facilities must await a decision on the type of screening that is to be adopted and the quantity of bypass water involved.

Transportation.

Of the several possible methods of transferring fish from the prototype screen structure to a safe point down river, which include open canal, pipe line, barge, and truck, we believe that the most flexible, most satisfactory, and possibly the least costly would be by tank truck. The fish are being transported by this method at the present time, and while the equipment and procedure could undoubtedly be improved upon, experience with the present equipment will lead to more adequate design.

RECOMMENDATIONS

Prototype Design.

1. Experiments should be made to develop a system of ports and risers that will effectively collect the species and size of fish at Tracy.

Two of the most promising solutions to the problem of screening the Tracy diversion require the use of belt screens with an effective system for collecting the fish during low velocity flows. Fish collection ports and risers at the sides of belt screens have been successful in collecting salmon fingerlings at locations other than Tracy, and there is every reason to believe that a properly designed system of ports and risers could be successful at Tracy.

2. Detailed studies should be made on the cause and cure of shock in striped bass. The possible existence of this condition among other species of fish should not be overlooked.

All of the screening solutions proposed require collection, holding, and transportation of the fish. The success of these operations will depend on the degree to which injury to the fish can be minimized. In connection with the use of high-velocity screening, the study should include a closer examination of the relative injury with and without collecting cups on the baskets of the belt-type screens, the possibility of injury in the process of flushing the fish off the screen, the effect of duration of impingement upon degree of injury, and the effect of velocity of impingement upon the degree of injury for each size and species of fish at Tracy.

3. Further studies on the reaction of fish to louvers should be made.

The present experimental flume is not adequate for making a valid test of the practical value of the louver principle for fish-screening purposes. A line of louvers in the prototype structure would need to be hundreds of

feet in length. It is essential, therefore, to know if the reaction of the fish to the louvers would be continually repeated when the fish are exposed to a long section of louvers. The minimum length of a line of louvers that should be used in testing the louver principle is, in our opinion, 100 feet.

The problems involved in this method of screening are both biological and hydrological and consequently hydraulic engineers as well as biologists should be assigned to the study.

4. If the results of exploratory experiments on electrical fish guiding indicate a possibility of success, tests should be undertaken in the present pilot channel intake of a full-scale electric screen.

Experiments on the use of electricity in directing fish movements are now in progress at Seattle. While it will be several years before all of these experiments are completed enough information may be available by 1954 to indicate whether a large scale field trial at Tracy should be attempted. The test proposed would screen the entire flow through the pilot channel. Such a test would provide an adequate measure of the practical use of electrical screening and of the power needed to operate such an installation.

5. The problem of holding, concentrating, and transferring fish to the transportation trucks should receive further study and tentative plans should be prepared as soon as possible.

Information on this subject is being obtained at the present time, however, more thought should be given to various possible installations in the final structure. Regardless of the method of screening adopted the fish will have to be held, concentrated, and transferred to truck (provided of course that trucks are used for transportation).

6. An early decision should be reached as to the means for transporting fish from Tracy to a point or points downstream.

It would appear that tank trucks offer the most versatile and practical method of transportation.

7. Consideration should be given to the possibility of moving the proposed site of the prototype screen structure to a point closer to the pumping plant.

Placement of the screen structure in the close proximity of the pumping plant would materially reduce the variation in flow through the screens due to tidal action.

Interim Period.

It has been pointed out earlier in this report that several years will elapse before the prototype screen structure will be completed after the final design has been determined. Reliance will have to be placed, therefore, upon the pilot screen structure for the protection of fish life until at least the spring of 1957 and possibly much longer. In making these recommendations we are concerned primarily with the protection of fish during this interim period, however, we realize that some of the recommendations are equally applicable to both the interim period and to the study of the problems related to the design of the final structure. The study of shock control is an example. We are also cognizant of the initial high cost of some facilities and the advisability of keeping to a minimum those facilities that would be utilized only during the interim period.

1. Ten additional belt screens should be installed in the pilot structure as soon as possible to replace all the screens except the two belt screens now in operation.

It is understood that two belt screens are on order at the present time and will be installed within a few months. However, even with a total of four belt screens, conditions for the protection of fish life will still be inadequate owing to the quantity of water being diverted

at the project. These new screens should be so designed as to provide for the washing or flushing off of the fish from the lower lips or cups of the screen baskets with one set of spray jets into a fish flume and the subsequent washing of the debris from the screen by a second set of jets into an independent flume.

2. At least one additional fish truck should be obtained for use in transporting fish from Tracy to a point down river.

Large numbers of fish are already being collected at the Tracy pilot screen structure, and a minimum of two trucks should be available so that in the event of a mechanical breakdown there will always be at least one fish truck available to transport the fish.

3. Consideration should be given to transporting and releasing fish during periods of high tide or during the first part of the ebb.

It is considered that the further down the river the fish are released the better their chance of survival will be, and fish released during the period of high tide would effectively be released further downstream than those released at low tide.